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A Health-Based Approach for Sampling Shallow Soils at Hazardous Waste Sites Using the $AAL_{soil\ contact}$ Criterion

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Strategies for sampling shallow soils at hazardous waste sites are employed primarily to evaluate levels and distributions of contamination. The ensuing analyses of potential public health impacts are therefore dependent on the sampling design rather than having the sampling design based on the data needs for evaluating potential public health impacts of shallow soil contamination. We define a specific objective that guides the sampling of shallow soils. The sampling results can thereby be directly employed to evaluate potential public health impacts from direct contact exposures to shallow soil contamination.

Introduction

The deleterious effects of toxic chemicals are expressed upon exposure of a biological receptor. Exposure media can include air, water, soils, and biota. Humans can be exposed to toxic chemicals residing in the contaminated media of exposure.

Exposures can occur where chemicals were disposed and can also occur at locations distant from disposal, after contaminants migrate or are transported through various processes. Exposure to toxic chemicals usually involves four elements (*1*): (*a*) a source and mechanism of chemical release to the environment, (*b*) a transport mechanism that moves the chemicals through the environment, (*c*) a point of potential exposure to the contaminated medium, and (*d*) an exposure route (e.g., inhalation, ingestion) at the point of exposure.

The characterization of a hazardous waste site should conclude with the determination of contaminant levels within media of exposure at existing and future potential points of exposure. Toxicological evaluations focus on developing criteria that delineate the potential public health impacts associated with exposure to a contaminated medium via one or more routes of exposure (*2*). Comparison of contaminant levels in media of exposure with health-based exposure criteria constitutes an analysis of possible adverse public health impacts because of contamination at a hazardous waste site.

Hazardous Waste Site Investigations

In the course of a typical investigation of an abandoned or uncontrolled hazardous waste site, many samples of soil are collected and analyzed for contaminant content. Objectives of such soil sampling efforts usually involve determining the presence or absence of contaminants, comparing contaminant distributions with ambient background levels, determining the extent of contamination, or verifying the attainment of a site mitigation criterion established for soil.

The California Site Mitigation Decision Tree Manual (*2*) and the U.S. EPA Remedial Investigation/Feasibility Study (*1*) provide guidance on evaluating whether or not an uncontrolled hazardous waste site poses a threat to the public. Both documents focus largely on the exposure of the public to contaminated air or groundwater. At many hazardous waste sites, exposure to contaminated shallow soil may present a significant threat to the public. However, guidance on how to address this medium of exposure has been very limited (*3,5*).

Recently, a methodology was established to develop a health-based standard known as the applied action level for direct contact ($AAL_{soil\ contact}$) for evaluating human exposure to shallow soil contamination (*6*). Using the $AAL_{soil\ contact}$ criterion requires that a potential site be sampled to yield information concerning

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the levels of toxicants at the point of exposure. Unfortunately, soil sampling efforts are typically not undertaken to achieve this objective.

A sampling objective and various sampling approaches available to meet this objective are presented in this paper. The sampling objective is motivated and shaped by the need to evaluate potential public health impacts of direct contact exposures to shallow soil contamination. This sampling approach is considered to be health-based since the sampling design is developed to collect the data necessary to determine potential impacts on public health, rather than focusing solely on evaluating the distributions of contaminants.

Exposure to Shallow Soils

Human exposure to toxic chemicals can occur through direct contact with contaminated shallow soils, resulting in an eventual intake of chemicals into the body. The term "direct contact" is used as a somewhat redundant descriptor to emphasize the evaluation of soil only as a medium of exposure. The $AAL_{soil\ contact}$ criterion, therefore is not used to evaluate soil as a reservoir for contaminants that might migrate into other media such as air or groundwater.

Environmentally persistent contaminants are often associated with shallow soil contamination. Volatile organic chemicals, such as benzene and trichloroethylene, are generally not observed in surface soils because of their propensities to escape into the atmosphere. Since direct contact exposures to soils contaminated with volatile organic contaminants typically do not occur, soil exposure criteria are not developed for this class of compounds.

The development of health-based exposure criteria for contaminants in soil, presented by Sedman (*6*), puts forth rates of exposure to shallow soils. By allocating the allowable daily intake for a particular chemical (mg/day) to the exposure rate to soils (g/day), the soil exposure criterion known as the $AAL_{soil\ contact}$ is derived.

Basic assumptions associated with development of an $AAL_{soil\ contact}$ include lifelong exposure to contaminated soils in a residential setting. The principal routes of exposure considered are ingestion and dermal contact. Additional exposure to contaminants in suspended particulates via inhalation is considered in the analysis of the air exposure pathway by employing the applied action level for air (AAL_{air}).

The $AAL_{soil\ contact}$ is based largely on two studies where soil samples were collected at various locations around residential structures. Daily rates of soil exposure were determined, based on the average concentrations of certain elements in these soil samples. Therefore the $AAL_{soil\ contact}$ criterion reflects exposure to soils throughout a large area around the residential structure and not to any one specific area or location.

Over an extended period of time, exposure to soils in a residential setting would be expected to occur throughout a significant portion of a residential lot. It is not anticipated that exposure to shallow soil over several decades would occur at a single location on a residential property. Therefore, based on the approach employed to develop the $AAL_{soil\ contact}$ criterion and the anticipated exposure that would occur over time in a residential setting, the average concentration over a significant portion of a residential lot is judged to represent the toxicant level at the point of exposure.

Other authors have suggested that average levels of soil contaminants are appropriate for evaluating potential health risks associated with shallow soil contaminated by hazardous wastes (*4,5*). However, the area representing the point of exposure was not established.

The Approach

Two exposure scenarios that can be evaluated through the proposed approach include situations where shallow soil contamination exists in a residential setting and also where shallow soil contamination exists on a property that might later be developed as residential. The probable average level of a contaminant in shallow soil at a given confidence interval is the appropriate value to be sought through sampling.

In California, various zoning jurisdictions have established a minimum area of a residential lot that is equivalent to 5000 ft^2. These zoning requirements also delineate setbacks of the residence from the property boundary. A significant area is viewed as the reasonable minimum area of the residence where activities resulting in exposure to soils would predominantly occur. A back yard would constitute such an area.

The results of a survey of various zoning and setback requirements throughout California are presented in Table 1. Based upon the setback requirements presented in that table, the significant portion of a residential property in California is taken to be 1000 ft^2 (20% of 5000 ft^2).

In reviewing the values presented in Table 1, it should be noted that in some instances site-specific conditions and local zoning practices may warrant that alternative dimensions be developed to define the significant area of a residential lot. For other states, local zoning practices could be employed to determine a significant portion of a residential property where exposures to soil would occur. However, the zoning requirements in California are probably consistent with practices elsewhere.

Table 1. Zoning requirements for single-family residential land use in selected jurisdictions throughout California.[a,b]

City or county	Minimum lot size, ft	Minimum front yard setback, ft	Minimum rear yard setback
Los Angeles County	5000	20	15 ft or 20% of average depth of shallow lot, but not less than 10 ft
Kern County	6000	25	5 ft
City of Bakersfield	6000	25	25 ft or 20% of the depth of the lot, whichever is less.
Alameda County	5000	20	20 ft
Yolo County	6000	25	25 ft
Sacramento County	5200	20	20% of average depth of lots less than 125 ft deep; never less than 10 ft for all one-story buildings.
San Diego County	6000	20	25 ft, equivalent to 25% of minimum size lot (60 times 100 ft).
City of Chico	6000	20	15 ft, equivalent to 15% of minimum size lot (60 times 100 ft).

[a]Based on information available in communications received from represented jurisdictions.

[b]Exceptions to zoning criteria are often made on a case-by-case basis.

Methods of Analysis and Sampling Designs

At least three methods of analysis and their associated sampling designs are available for executing a statistical approach to sampling shallow soils. These methods and sampling designs include the stratified-random method, the multi-stage stratified-random method, and the geostatistical analysis, including kriging.

Many considerations are involved in planning a soil sampling episode. Prior to developing a sampling plan, background information and previous investigations of the site should be evaluated to focus and improve the efficiency of the soil sampling effort. Statistical considerations include the variability of contaminants in soils, advantages and limitations of various statistical approaches, assumptions concerning population distributions, and techniques and strategies for compositing samples. Additional planning considerations include applying professional judgment and experience, iterative or phased approaches to sampling, costs, and quality assurance/quality control. These and other considerations have been discussed previously, and only brief reviews of three sampling designs are intended (*2,4,7–11*).

No single sampling design has been demonstrated clearly superior in terms of accuracy and reliability for results on hazardous waste sites. An investigator should therefore evaluate the advantages of each particular design applied in the iterative manner recommended to evaluate hazardous waste sites (*2*). The use of more than one sampling design in order to compare and demonstrate the reliability of a given set of results should be considered.

Stratified-Random Sampling

The stratified-random sampling design requires that samples be collected at locations selected randomly from within a given area or stratum. Statistically determined distributions of contaminants within two or more strata are compared with one another or with a predetermined criterion. For a single contaminant this would simply require comparison of the average contaminant level determined over 1000 ft^2 with the $AAL_{soil\ contact}$ for that compound.

A straightforward application of the stratified-random sampling design requires that a site be divided into strata with surface area of 1000 ft^2 each. Every stratum would be sampled with at least two randomly located sampling points. Increasing the minimum number of samples collected per stratum from two to four should markedly improve the precision of results, based on the methodology for calculating precision with a given number of samples and an assumption of a normally distributed population. Therefore, a minimum of four samples per stratum can be recommended when allocating financially constrained total available samples. Other methods of determining the number of soil samples to be collected have been based on the known or suspected variability of the contamination (*7–9,11*).

The stratified-random sampling design can be modified so that strata need not be contiguous, nor covering the entire property when only portions of a property are of interest. Where contamination is suspected to be confined to an area of less than 1000 ft^2, sampling results from two adjacent strata can be combined to provide an estimate of the average levels of contaminants throughout a 1000 ft^2 area.

Multi-Stage Random Sampling

Multi-stage stratified-random sampling builds additional levels of randomness into the selection of sample locations. Areas thought to be contaminated and uncontaminated would be organized to consist of several strata each. Strata selected at random from within each area would then be sampled randomly. Thus, multi-stage, stratified-random sampling designs can be used to attempt to maximize the information obtainable with a limited number of sampling opportunities allocated to investigate a relatively large area.

Kriging

Geostatistical methods have been used to characterize phenomena that are spatially variable, such as deposits of minerals of economic importance (*12*). Kriging is one form of geostatistical analysis that has been discussed with regard to hazardous waste sites; it produces distributions of variables as well as the errors associated with interpolated values.

Kriging has the appealing characteristic of not necessarily imposing artificial boundaries or compartments on the site, such as with the development of strata. Rather, the contours developed to represent the distribution of contaminants could be evaluated throughout surface areas greater than 1000 ft^2. A systematic sampling design based upon a grid is typically recommended for selecting sample locations. Sampling to develop the semivariogram describing the spatial variability of contaminants may also be necessary.

Kriging data to produce estimates of average levels within three-dimensional blocks or two-dimensional panels has also been discussed (*13*). Such methods of analysis would seem to have direct application to hazardous waste sites, having defined 1000 ft^2 as the appropriate dimension of surface area.

The Risk Appraisal Mechanism

To evaluate potential public health impacts of shallow soil contamination requires a measure of the amounts of contaminant to which a human being could be exposed and a methodology for evaluating the implications of such exposures. A methodology for evaluating the implications of exposures to toxic chemicals associated with abandoned or uncontrolled hazardous waste sites, referred to as the Risk Appraisal Mechanism (*2*), is discussed below.

The Risk Appraisal Mechanism consists of three numerical tests employed to evaluate the potential public health impacts of all single medium-single chemical exposures, all multiple media-single chemical exposures, and all multiple media-multiple chemical exposures for chemicals with similar toxicological effects. The exposure criterion employed in the risk Appraisal Mechanism is known as the Applied Action Level (AAL). Values of the AAL criterion for air (AAL_{air}), water (AAL_{water}) and soil ($AAL_{soil\ contact}$) and methods to derive exposure levels have been described previously (*2,6,14,15*).

The three tests of the risk Appraisal Mechanism are written as:

Test 1: Single medium—single chemical exposures

If $C_{medium}/AAL_{medium} > 1$, then

the test fails, a sensitive biological receptor is considered to be at risk to an adverse effect, and a risk management process should be initiated.

Where medium = exposure medium (air, water, soil, biota)

C_{medium} = concentration of a toxic substance in a medium of exposure.

AAL_{medium} = AAL expressed as a concentration of the toxic substance in the medium.

Test 2: Multiple media—single chemical exposures

If $\sum_{medium=1}^{n} (C_{medium}/AAL_{medium}) > 1$, then

the test fails, a sensitive biological receptor is considered to be at risk to an adverse effect, and a risk management process should be initiated.

Test 3: Multiple media—multiple chemical exposures for chemicals with similar toxicological effects

If $\sum_{sub=1}^{z} \sum_{medium=1}^{n} \frac{C_{medium,sub}}{AAL_{medium,sub}} > 1$, then

the test fails, a sensitive biological receptor is considered at risk of an adverse effect, and a risk management process should be initiated.

Where, sub = toxic substance.

The risk appraisal mechanism allows for the evaluation of potential public health impacts of exposures to shallow soils contaminated with hazardous wastes by employing the $AAL_{soil\ contact}$. Proper characterization of a hazardous waste site yields the values of C_{soil} to be employed in the risk appraisal mechanism.

Using Sampling Results

Historically, the questions to be answered through sampling shallow soils at hazardous waste sites have been formulated only in terms of determining contaminant levels. The overall objective of any sampling should focus on collecting the data necessary to evaluate the potential public health implications of exposure to contamination. The specific questions answered through sampling of shallow soils in accordance with the aforementioned health-based approach that allow this overall objective to be realized are the following: *a*) Is the average concentration of a chemical, determined at a specified confidence interval in shallow soils in any area corresponding to 1000 ft^2 above the value of $AAL_{soil\ contact}$ for that chemical? *b*) If there are other significant media of exposure, do the cumulative chemical exposures fail test 2 of the risk appraisal mechanism? *c*) If there are chemicals with similar toxicological effects, do the *cumulative exposures fail* test 3 of the risk appraisal mechanism?

By linking the sampling effort to the risk appraisal mechanism, the goals for sampling shallow soils are consistent with the overall objective of site characterization, which is to allow an analysis of the potential adverse impacts associated with toxic chemicals at a particular hazardous waste site. The health-based approach to shallow soil sampling does not focus on *evaluating only a single elevated measurement* of a chemical in soil. Moreover, extensive sampling of both contaminated and noncontaminated regions, so as to statistically dilute the average level of contamination calculated, is not appropriate. Having defined 1000 ft^2 as the point of exposure and the average as the level of exposure input to the risk appraisal mechanism, the interpretation of results becomes more objective and less manipulable.

Summary

Strategies employed to sample soils during hazardous waste site investigations usually focus on collecting data from which an assessment of the extent and distribution of contaminants might be made. Typically, the sampling design employed has not been developed specifically to address questions or hypotheses as to *how the contamination may potentially* impact the public.

An approach to soil sampling has been presented in which the intended use of the data motivates and directs the sampling effort. The intended use of the data is to evaluate potential public health implications of direct contact exposures to shallow soil contamination. That evaluation is accomplished by employing the average levels of contaminants over 1000 ft^2 areas in the risk appraisal mechanism, using the values of $AAL_{soil\ contact}$ for the contaminants of concern. Thus, an objective for sampling and an approach for collecting and interpreting the data describing shallow soil contamination at hazardous waste sites in terms of potential public health impacts of direct contact exposures to contaminants have been developed.

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